A Heuristic Approach for Economic Dispatch Problem in Insular Power Systems

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Abstract. Insular power systems are characterized by their isolated geographical location, which makes their interconnection with other power systems a challenging task. Moreover, these islands have important renewable resources that allow the reduction of generation costs and greenhouse gas emissions (GHE). To guaranty the quality, flexibility and robustness of the electrical framework, the representation of renewable power forecasting error by scenario generation or even the implementation of demand response tools have been adopted. In this paper, the failure events of a specific unit are considered according to its capacity. Then, using the forced outage rate, the probability of each failure event is computed. Results of energy not supplied and fuel consumption cost are determined by applying probabilistic concepts, while the final results are obtained by fitting and evaluating a nonlinear trend line carried out using the previous results, resulting in a proficient computational tool compared with classical ones.

Keywords: Insular power systems, power system reliability, probabilistic economic dispatch, wind power forecasting error.

1 Introduction

Isolated geographical location and good potential to develop renewable power generation systems are two of the important topics that have driven the integration of renewable energy sources into insular power systems. In fact, in insular power systems the major problem is the high generation cost related to the type of fossil fuel used and its transportation. However, in most of the cases, there are available endogenous resources that allow reducing the generation costs and GHE. Such concerns and characteristics have motivated the development and implementation of more renewable energy sources, such as wind energy, among others depending on the island location on the globe. Notwithstanding, one of the main obstacles is related to the legislation and administrative barriers [1], which can threaten the profitability of electric production.

One of the solutions that have been widely suggested is the penetration of energy storage systems (ESS) to face these problems, due to the fact that ESS can improve the flexibility of the electrical system and allow more penetration of renewable energy sources. Nonetheless, several factors such as capacity tariffs, wind potential and investment costs affect the economic viability of those projects [2]. Other valid way is the implementation of demand response (DR) approaches, which allows also the manipulation of a system load curve.

One other option, which is the focus of this paper, consists in introducing the uncertainty of renewable power forecasts on economic dispatch (ED) problems. For several years now, wind power forecasting error has been represented by scenario generation as a flexible approach, which enables a representation of cross-temporal characteristics of the wind power time series, influencing the spinning reserve requirements [3].

In [4], a scheduling approach based on scenario generation was proposed. In this model, several scenarios of wind power production, load demand and forced unit outages are randomly generated considering the auto-correlated nature of each time series. Then, the optimal scheduling is determined by using a mixed integer stochastic optimization algorithm, where the main objective is to minimize the expected generation cost. In [5] and [6], the proposed approaches introduce the wind power generation in the ED problem as a restriction in the optimization problem. Based on the probabilistic infeasibility and using the Lagrange multiplier method, the influence of wind power behavior and penetration level on total generation cost is analyzed. In [7], the effects of wind power generation in the ED problem are studied introducing NO_x emissions modelled using an incomplete gamma function. In [8], a scheduling approach is presented as a dynamic programming problem, while wind power behavior is represented as a first-order Markov process. In [9] an ED approach based on fact that the aggregation of wind power generation reduces its forecasting error is presented, allowing the mitigation of the stochastic relations in the optimization problem.

In [10], an approach incorporating load forecasting error, forced outages of generation units and transmission systems by means of a Monte Carlo simulation (MCS) is presented, enabling the estimation of the optimal reserve required in the solution of unit scheduling problems taking into account a determined reliability level. In [11], a scheduling approach based on mixed-integer linear programming (MILP) to determine the optimal frequency-regulating reserve is proposed, while in [12] another approach based on mixed-integer programming (MIP) and MCS, considering N-1 contingencies is presented. In [13], a short-run ED approach is proposed, where the different states that take place during the contingency event are analyzed and represented as a linear programming problem.

In this paper, a new approach incorporating the renewable power forecasting error and the power system reliability in the analysis of generation cost, composed of fuel consumption cost (FCC) and energy not supplied (ENS), is developed and presented. In proposed approach, the failure events of a unit or multiple units are considered according to its generation capacity. Then, using the forced outage rate (FOR), the probability of each failure event is computed. Meanwhile, a transformation is applied to the probability of each event, and therefore the sum of the probability of all considered events is one. Initial results of ENS and FCC are determined by applying probabilistic concepts, while the final results are obtained by fitting and evaluating a nonlinear trend line carried out using the initial results.

2 Contribution to Cloud-based Engineering Systems

Cloud-based solutions (CBS) can provide an easier and improved data connection with focus on remote tools, making suitable the concepts of the proposed study. CBS can enable a more efficient behavior of the computational resources and the information availability for the ED problem in an accurate time frame. Actually, CBS can provide an excellent interconnection to share in an efficient way the information between all electrical industry players'. A fast share of information is more and more required in the energy systems field, where data can be stored in a safe way to be ubiquitously accessed whenever needed, which is a valuable benefit of cloud-based engineering systems. Furthermore, the shared tools can improve the flexibility, accuracy and robustness of overall electrical framework, helping to improve the advent of electrical smart grids, namely in islanded location.

3 Insular Power System Characterization

Typically, insular power systems are characterized by a small number of conventional generation units, fewer than 26 units, and installed capacity lower than 2000 MW. Frequently, conventional generation units employed are steam turbines, combined cycle gas turbines, diesel engines, open cycle gas turbines and renewable energies [14]. In most cases, such units use heavy fuel oil and/or light fuel oil, although the integration of liquefied natural gas [15], [16]. Moreover, the cycling of power production as a consequence of integration of stochastic renewable power sources, such as wind power, produces an increment in the number of failure events and maintenance cost. Normally, in mainland power systems, units employed to supply peak loads could have a forced out rates (FOR) of 0.02%, cycling units could have 10.15%, while base load units could have 3.69%, on average [17]. The 5-unit system under study in this paper is described in Table 1 [18], representing minimum and maximum output power, curve consumption parameters of units, and down/up ramps.

Moreover, units 1 and 2 are considered as peak units, unit 3 is considered as cycle unit, and units 4 and 5 are considered as base load units, representing a real small insular electrical framework. The load demand to be supplied at time t is 450 MW±10%, while the number of intervals selected for discretization was ($B = 7$).

Table 1. Main characteristic of 5 units of insular power system.

n	P_{min}^n (MW)	P_{max}^n (MW)	a_i ($/h)	b_i ($/MWh)	c_i ($/MW^{2}h)	DR_n & UR_n (MW/h)	*FOR*
1	5	50	30	27.89	0.0143	48	0.01
2	10	50	27	19.00	0.0085	48	0.01
3	10	70	27	18.10	0.0081	114	0.12
4	20	120	25	12.69	0.0046	114	0.05
5	70	200	20	9.66	0.0014	150	0.05

4 Economic Dispatch Problem

The mathematical formulation of the ED problem is briefly described afterwards, where the uncertainty related with the integration of wind power forecasting (*WPF*) and the reliability of the power system are both incorporated in order to determine the expected value of ENS ($E\{ENS^t\}$) and FCC ($E\{FCC^t\}$) in a determined time instant t. The uncertainty of WPF is directly reflected on the value of net load (L^t). FCC could be modelled according to (1):

$$C_i^t = a_i + b_i(P_i^t) + c_i(P_i^t)^2 \tag{1}$$

where a_i, b_i and c_i are the coefficients of fuel consumption of each unit i, C_i^t is the FCC of unit i at time t. The definition of expected generation cost is expressed in (2):

$$E\{GC^t\} = E\left\{\sum_{n=1}^{N} C_n^t\right\} + VOLL \times E\{ENS^t\} \tag{2}$$

where *VOLL* is the value of lost load, $E\{\bullet\}$ is a function that represents the estimation of expected value of a determined variable. Also, the ED problem is constrained to the operational limitations of each unit, which typically are modelled according to their minimum and maximum power output operation, and up/down ramp constraints between the present state and previous state in time. Furthermore, it is important to note how $E\{GC^t\}$ is strongly dependent on FCC and ENS, so it is of the utmost importance to determine such values ($E\{FCC^t\}$ and $E\{ENS^t\}$) in an efficient and proficient way.

5 Proposed Approach

The proposed approach in this paper estimates the main components of the generation cost structure (FCC and ENS). The first step determines the order in which units are going to fail. This is carried out due to the number of possible combinations of failure events that increases exponentially until 2^N. In order to avoid this problem, a limited number of units to be failed (D) is selected according to a determined criterion. In the second step, the normal operation is modeled as 1 and the failure condition as 0, so all possible combinations of failure events are estimated only considering the first-D units. This approach allows all computational efforts to be concentrated only in the failure of units of interest. In the third step, for each combination of event failure, the ED problem is solved only incorporating the forecasting error, obtaining initial values of $E\{ENS^t\}$ and $E\{FCC^t\}$. Also, a transformation is introduced to deal with the sum of probabilities, obtaining the appropriate weights proportional to their corresponding probabilities. Then, initial values of $E\{ENS^t\}$ and $E\{FCC^t\}$ incorporating forecasting error and system reliability can be obtained by using traditional probabilistic theory. Figure 1 summarizes the proposed algorithm considering up to five points (initial values of $E\{ENS^t\}$ and $E\{FCC^t\}$).

5.1 Introducing Forecasting Error in the Proposed Approach

Assuming that the forecasting error and (L^t) are modelled using a Gaussian PDF, such PDF is incorporated in the optimization problem by dividing it in several intervals or power classes (B) [19]. A classical ED problem [20] could be solved for each element of the set of load values described above, obtaining the corresponding set of ENS values and FCC values.

Then, the part of $E\{ENS^t\}$ and $E\{FCC^t\}$ related to the forecasting error ($E\{ENS^t\}^{FE}$ and $E\{FCC^t\}^{FE}$) could be estimated using (3) and (4):

$$E\{ENS^t\}^{FE} = \sum_{b=1}^{B} (ens_b^t)(P_r\{l_b^t\}) \tag{3}$$

$$E\{FCC^t\}^{FE} = \sum_{b=1}^{B} (fc_b^t)(P_r\{l_b^t\}) \tag{4}$$

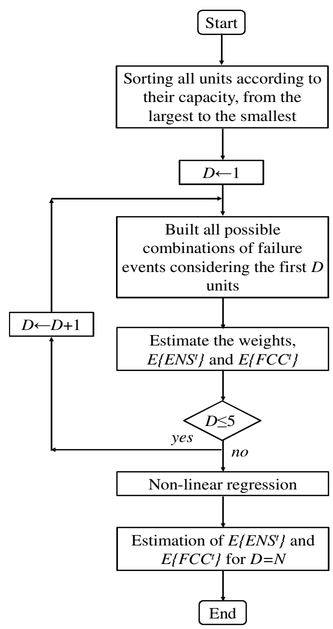

Fig. 1. Algorithm of proposed approach.

5.2 Introducing Forced Outage Rate in the Proposed Approach

The power system reliability is incorporated by introducing a transformation applied to the probability of occurrence of a determined number of possible failure events, allowing the substitution of the probabilities of some determined failure events by weighted values whose addition is 1. Then, the ED problem is solved according to subsection 5.1 where the expected value of ENS and FCC that corresponds to a row j considering only the forecasting error ($E\{ENS^t\}_j^{FE}$ and $E\{FCC^t\}_j^{FE}$) are obtained. Also, the values $E\{ENS^t\}$ and $E\{FCC^t\}$, which incorporate forecasting error and system reliability considering the failures of first-D units, are obtained by using (5) and (6):

$$E\{ENS^t\} = \sum_{j=1}^{H} (E\{ENS^t\}_j^{FE})(T_j) \tag{5}$$

$$E\{FCC^t\} = \sum_{j=1}^{H} (E\{FCC^t\}_j^{FE})(T_j) \tag{6}$$

6 Case Study

The 5-units case study has been presented and analyzed in order to illustrate the approach proposed in this paper, being adapted from other cases studies frequently used in the technical literature. Figure 2 shows the comparison of $E\{ENS^t\}$ between the results obtained from the MCS approach, considering 10,000 trials and the solution obtained from the application of probabilistic theory evaluating all possible combinations of event failures and the discretization of L^t in nine intervals (B = 9), and the proposed approach for D = 1, 2,.., 5. It is possible to see how there is a small difference between MCS and the probabilistic solution due to the fact that MCS is not considering all possible combinations. Moreover, it is possible to see how the initial values of $E\{ENS^t\}$ converge to the probabilistic solution as the values of D tend towards N; this is the most important effect of the transformation applied. Figure 3 presents a similar comparison for the estimation of $E\{FCC^t\}$, where the proposed approach has a tendency to lean towards the probabilistic solution.

In order to illustrate the approach to determine the optimal spinning reserve, the generation units presented in Table 1 have been sequentially committed according to their economic priority to supply a load demand of 60000 kW±5%. The obtained results were used later to build the curves presented in Figure 4, which describes the behavior of ENS and FCC. The behavior of $E\{GC^t\}$ built according to equation (2) is shown in Figure 5 for a VOLL between 0.2 €/kWh and 6 €/kWh.

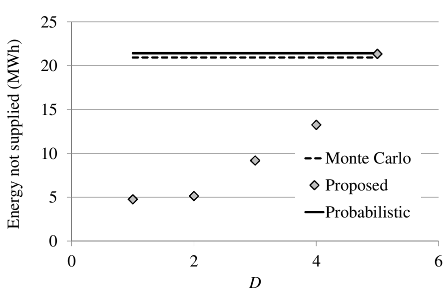

Fig. 2. Evolution of ENS comparison between MCS and the proposed approach.

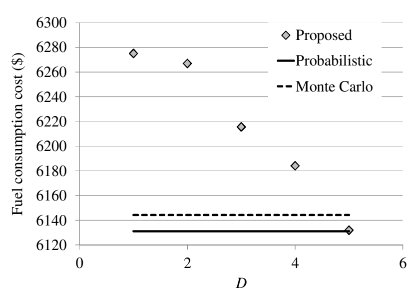

Fig. 3. Evolution of FCC cost comparison between MCS and the proposed approach.

Table 2. Probabilistic Priority List Results.

Variable	*MCS*	*Proposed*	*|Error|*	*|Error (%)|*
E{ENS} (kWh)	8810.622	9797.0216	986.3992	11.19557
E{FCC} (€)	11603.703	11593.558	10.145	0.087432
Time (s)	205.338	10.813	------	------

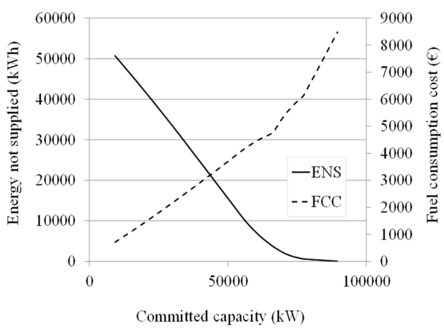

Fig. 4. Behavior of ENS and FCC with the committed capacity.

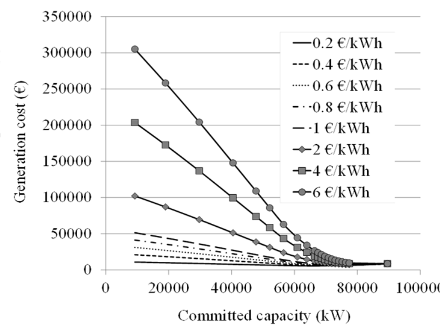

Fig. 5. Generation cost for several VOLL values.

7 Conclusion

The integration of renewable energy sources in insular power systems is limited by their ability to accommodate and manage the variability of such stochastic sources. Moreover, determining the appropriate amount of spinning reserve considering the uncertainty of renewable power forecasting and system reliability is of the utmost importance. Hence, this paper has incorporated in ED problem such topics in order to determine FCC and ENS values in a proficient manner, taking advantage of the tendency of initial values towards the probabilistic solution that could be provided by the CBS system. The results obtained showed how the proposed approach allows the values of $E\{ENS^t\}$ and $E\{FCC^t\}$ to be obtained with a very reasonable error in just a few seconds, compared to the solution obtained from the MCS approach.

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